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THE USE OF NON-METRICAL SKULL CHARACTERS FOR ANALYZING GEOGRAPHICAL VARIATION IN THE COMMON DOLPHIN, *Delphinus delphis* PART I: SELECTION OF CHARACTERS

by

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Jay Barlow and Mikhail V. Mina

ADMINISTRATIVE REPORT LJ-88-20

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PART 1: SELECTION OF CHARACTERS

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INTRODUCTION

A previous study of non-metrical cranial variation in dolphins compared large samples of pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*S. longirostris*) from single purse seine hauls ("schools") on yellowfin tuna in the eastern tropical Pacific, to examine possible variation among schools (Perrin et al., 1982; Yablokov et al., 1983). The results were equivocal, with some proportion of the estimated variation among schools possibly due to differences among observers in scoring techniques and drift in character-state evaluation with time (Perrin, Mina, Walker and Barlow, unpub.). The purpose of the study reported here is to apply the approach to samples of dolphins that came from localities known to be reproductively isolated from each other, common dolphins (*Delphinus delphis*) from the eastern tropical Pacific and from the Black Sea, with emphasis on repeatability of scoring. The results of the non-metrical analysis will be compared with the results of a more traditional analysis of skull measurements of the same samples; if the non-metrical method cannot discriminate between the two samples at least as well as the metrical method, then there will be little point in pursuing it farther. The study also includes analysis of correlations between characters, with the objective of reducing the character set without loss of useful information, and analysis of correlations of the characters with sex of the specimen, to allow consideration of the bias introduced by sexually dimorphic features into comparisons of samples with different sex ratios (Yablokov et al., 1983).

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This report describes the non-metrical characters (developed by examination of the eastern Pacific sample), the analysis of variation between scorers and the analysis of correlations between characters and with sex. A future report will include the non-metrical and metrical comparisons of the samples from the eastern Pacific and the Black Sea and the comparative evaluation of the two methods.

MATERIALS AND METHODS

The Sample

The 73 skulls (46 male and 27 female) included in the analyses are in the marine mammal collection of the U. S. National Museum of Natural History in Washington, D. C. They are from dolphins captured in nine purse-seine hauls by several commercial tunaboats over a period of three weeks in the same general area in oceanic waters off Central America in the eastern tropical Pacific (Table 1). The common dolphins in this area are thought to belong to a single breeding population (Perrin et al., 1985).

Only adult skulls were included. The criterion of cranial adulthood used was presence of fusion of the premaxillaries and the maxillaries at the rostrum (Perrin, 1975).

The Characters and the Data Collection

We began with the characters described in Perrin et al. (1982). Upon examination of Delphinus material at the Southwest Fisheries Center and the USNM material, WFP and AVY deleted some of the characters and added others, to arrive at a total of 62. A number of additional characters were considered but not included, because of very low variability or difficulty of scoring. WFP and AVY then each scored the 73 skulls independently. After compilation of the results, they conferred on the more difficult characters, dropping some and modifying others. Several new characters were also added. At this point, some of the characters were redefined so that they had three states (one of which was "intermediate" or "uncertain"). The character-state definitions were revised to improve repeatability. WFP and AVY then each rescored the skulls using the new set of 52 characters, which are described in Appendix 1.

Table 1. Specimens used in study of non-metrical cranial variation in Delphinus delphis. USNM = U. S. National Museum.

Specimen (USNM No.)	N	Locality	Date
487766-67,69-70, 73-82	14	9 00'N, 84 10'W	13 Apr 1973
487807,09-12,15, 17-26,28-30	19	8 25'N, 84 00'W	16 Apr 1973
487840	1	9 18'N, 84 46'W	20 Apr 1973
500060-61,65-66	5	8 08'N, 87 54'W	31 Mar 1973
500069-80,82-85, 87-88	18	7 32'N, 83 54'W	1 Apr 1973
500092	1	7 25'N, 84 02'W	8 Apr 1973
500116	1	8 14'N, 83 15'W	4 Apr 1973
500315-16,20-23, 34-39	12	7 45'N, 90 50'W	12 Apr 1973
500340-41	2	8 40'N, 84 32'W	12 Apr 1973
Total	73		

The two final sets of scorings were used in the analyses described below.

Methods Used for Correlation Analyses

It is to be expected that at least some of the non-metric variables that were scored would be highly correlated to others. In such cases, it may be possible to drop one or more characters without losing significant information. When using metric variables, the Pearson product-moment correlation coefficient is typically used to describe such inter-relationship between variables. We used a non-metric analog to the Pearson statistic which calculates a coefficient of correlation based on a chi-square approach. The coefficient, R, can have values ranging from 0 (no correlation) to 1.0 (perfect correlation). It is calculated as

$$R^2 = \frac{\text{chi-square value}}{\text{maximum possible chi-square}}$$

The significance of the resulting correlation was determined by applying a chi-square contingency test. Correlations for the 52 characters were calculated separately for the data collected by WFP and AVY. Character states with fewer than 5 observations were excluded from the statistical tests. Correlation coefficients were therefore not calculated for some characters which had only two states with observations (a common state and a very rare state). For purposes of the analyses, the states of characters with more than three states (i.e., numbers of foramina or fenestrations) were aggregated into three pooled "states", e.g, 1-3, 4-6 and 7-9 foramina for character no. 8.

The same approach was used for analysis of correlations with sex of the specimen.

RESULTS

Comparison of Observers

Agreement between WFP and AVY in the first round of scoring ranged between 100% and 55-60% for the initial 62 characters (Figure 1a). After detailed discussion of the individual characters, 18 were dropped from the set because of low agreement, low variability or problems of character-state definition. Seven new characters were devised and added to the

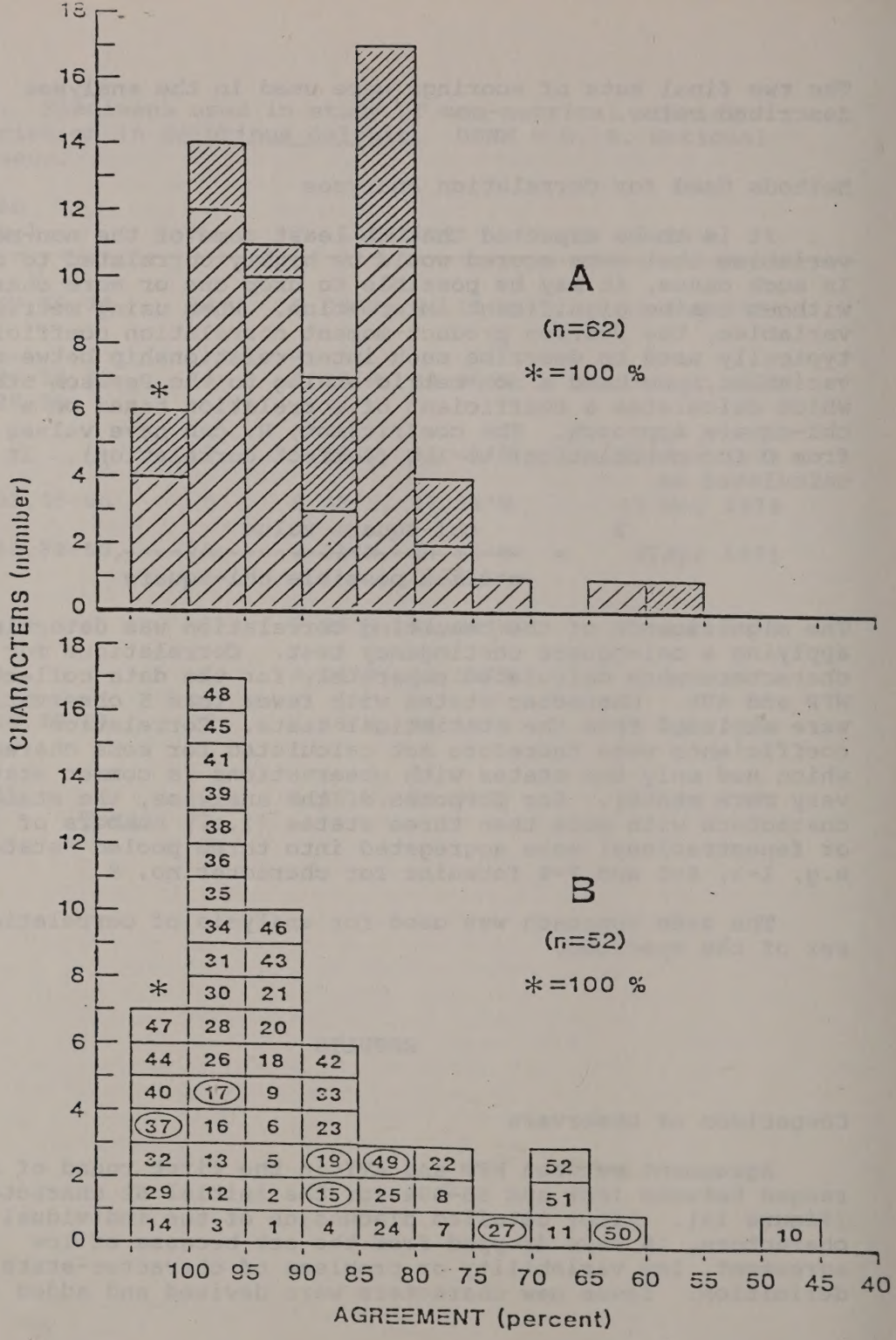

Figure 1. Histograms of percent agreement between WFP and AVY in (A) first round of scoring and (B) second round of scoring 73 skulls of Delphinus delphis for non-metrical characters. In A, shaded portions represent characters deleted for the second round. In B, numbers represent characters as listed in Appendix 1; circled characters were added as new characters for the second round.

set. Agreement in the second round of scoring was better (Figure 1b), but there was still very significant disagreement (more than 10%) for about 1/3 of the characters.

Correlations Among the Characters

The frequency distributions for the various character states are given in Table 2. The correlation coefficients for all pair-wise comparisons of variables are given in Table 3 for the WFP data and Table 4 for the AVY data; 554 correlation analyses were possible (the number of observations for each state of the characters was 5 or greater) for the former and 583 for the latter. The total number of significant correlations ($p < 0.05$) between variables was 44 (WFP) and 46 (AVY). The expected number of significant comparisons given 550-600 pair-wise tests is approximately 28-30 by chance alone. However, 19 of the significant correlations were common to the WFP data and the AVY data; only 1-2 correlations would be expected to occur in both data sets due to chance alone (0.05 X 0.05 X 595). Six (WFP) and 7 (AVY) of the significant correlations occurred with paired left/right characters for the same skull feature; of these 5 were present in both data sets. We conclude that correlations between the characters are significantly more common than would be expected by chance alone. An appreciable amount of the redundancy between variables can be eliminated by using only one of a left/right pair of characters.

Correlations with sex of the specimen

For the WFP data set, 34 analyses of correlation of the characters with sex were possible; for the AVY set, 36 were possible. Four characters were significantly correlated with sex in the WFP data set (Table 3) and 5 in the AVY set. Only 1-2 characters could be expected to be significantly correlated with sex by chance alone. Two characters, nos. 4 and 39 in Appendix 1, were correlated with sex in both data sets; these are good candidates for characters to be avoided in comparisons of samples with different or unknown sex compositions.

REDUCTION OF THE CHARACTER SET

Based on the results of the comparisons of observers, 18 of the 52 characters will not be used in the comparison of the eastern Pacific and Black Sea samples. These are the characters for which observer agreement was less than 90% in the last comparison round: nos. 4, 7, 8, 10, 11, 15, 19, 22, 23, 24, 25, 27, 33, 42, 49, 50, 51 and 52 in Appendix 1.

FREQUENCY DISTRIBUTION OF THE STATES OF THE VARIABLES:

VAR	1	2	3	4	5	6	7	8	9	10
-1	0.630	0.370								
0	1.000									
1	0.425	0.575								
2	0.301	0.699								
3	0.411	0.589								
4	0.562	0.425	0.014							
5	0.260	0.740								
6	0.452	0.548								
7	0.356	0.630	0.014							
8	0.370	0.178	0.014	0.000	0.000	0.000	0.000	0.000	0.438	
9	0.370	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.603	
10	0.000	0.014	0.000	0.068	0.178	0.452	0.151	0.123	0.014	
11	0.000	0.000	0.000	0.082	0.233	0.356	0.219	0.110		
12	0.123	0.877								
13	0.014	0.986								
14	0.904	0.096								
15	0.219	0.781								
16	0.082	0.918								
17	0.027	0.973								
18	0.890	0.110								
19	0.452	0.548								
20	0.726	0.274								
21	0.151	0.849								
22	0.521	0.479								
23	0.890	0.110								
24	0.630	0.370								
25	0.589	0.411								
26	0.877	0.123								
27	0.414	0.571	0.014							
28	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.973	
29	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.959	
30	0.877	0.068	0.055							
31	0.901	0.099								
32	0.056	0.917	0.028							
33	0.164	0.836								
34	0.932	0.055	0.014							
35	0.932	0.068								
36	0.932	0.068								
37	0.041	0.959								
38	0.639	0.097	0.264							
39	0.890	0.110								
40	0.959	0.041								
41	0.041	0.959								
42	0.250	0.750								
43	0.027	0.973								
44	0.014	0.986								
45	0.068	0.932								
46	0.068	0.932								
47	0.973	0.027								
48	0.986	0.014								
49	0.521	0.411	0.068							
50	0.458	0.472	0.069							
51	0.000	0.000	0.192	0.411	0.356	0.027	0.014			
52	0.000	0.000	0.192	0.507	0.219	0.055	0.014	0.014		

Table 2. Frequency distribution of character states as scored by WFP (left) and AVY (right).

FREQUENCY DISTRIBUTION OF THE STATES OF THE VARIABLES:

VAR	1	2	3	4	5	6	7	8	9	10
-1	0.630	0.370								
0	1.000									
1	0.411	0.589								
2	0.288	0.712								
3	0.411	0.534	0.055							
4	0.466	0.479	0.055							
5	0.247	0.753								
6	0.438	0.562								
7	0.205	0.493	0.301							
8	0.438	0.164	0.027	0.000	0.000	0.000	0.000	0.000	0.370	
9	0.356	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.616	
10	0.000	0.014	0.000	0.123	0.219	0.342	0.164	0.110	0.027	
11	0.000	0.000	0.000	0.096	0.329	0.288	0.205	0.082		
12	0.110	0.877	0.014							
13	0.014	0.986								
14	0.836	0.082	0.082							
15	0.219	0.726	0.055							
16	0.110	0.890								
17	0.041	0.959								
18	0.890	0.110								
19	0.548	0.452								
20	0.671	0.219	0.110							
21	0.151	0.849								
22	0.658	0.315	0.027							
23	0.986	0.000	0.014							
24	0.616	0.384								
25	0.603	0.397								
26	0.819	0.042	0.139							
27	0.139	0.750	0.111							
28	0.055	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.945	
29	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.959	
30	0.861	0.069	0.069							
31	0.817	0.127	0.056							
32	0.055	0.918	0.027							
33	0.164	0.699	0.137							
34	0.781	0.082	0.137							
35	0.918	0.082								
36	0.918	0.082								
37	0.041	0.959								
38	0.690	0.141	0.169							
39	0.890	0.110								
40	0.959	0.041								
41	0.041	0.959								
42	0.233	0.767								
43	0.082	0.918								
44	0.014	0.986								
45	0.055	0.918	0.027							
46	0.068	0.904	0.027							
47	0.973	0.027								
48	0.986	0.014								
49	0.375	0.458	0.167							
50	0.384	0.370	0.247							
51	0.000	0.000	0.192	0.521	0.247	0.027	0.014			
52	0.000	0.000	0.164	0.479	0.315	0.014	0.014	0.014		

CORRELATION COEFFICIENTS BETWEEN VARIABLES BASED ON CHI-SQUARE:

	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	2
-1	100																												
0	-1	-1																											
1	3	-1	100																										
2	0	-1	(76)	100																									
3	12	-1	7	11	100																								
4	(28)	-1	1	8	(73)	100																							
5	6	-1	0	1	13	1	100																						
6	1	-1	16	11	3	6	(40)	100																					
7	1	-1	10	12	14	3	(50)	0	100																				
8	12	-1	(25)	(26)	(24)	10	16	24	17	99																			
9	(23)	-1	1	8	8	15	(24)	0	14	20	100																		
10	20	-1	8	16	13	6	17	15	21	13	17	100																	
11	11	-1	6	17	13	6	19	18	19	16	12	23	100																
12	11	-1	6	2	(36)	(32)	(34)	(24)	(32)	10	22	10	19	100															
13	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1														
14	15	-1	9	11	20	19	1	7	1	6	16	21	12	1	-1	100													
15	21	-1	18	20	9	0	13	8	4	3	6	6	12	9	-1	6	100												
16	8	-1	4	12	14	4	4	12	1	12	13	13	14	11	-1	7	3	100											
17	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1										
18	9	-1	5	5	6	4	10	(23)	1	(25)	8	15	(26)	13	-1	3	(23)	10	-1	100									
19	21	-1	11	18	8	10	3	16	2	5	12	14	22	8	-1	1	(38)	2	-1	12	100								
20	8	-1	3	13	7	14	12	(24)	7	14	8	18	20	4	-1	21	(25)	15	-1	11	(43)	100							
21	7	-1	(28)	(27)	4	5	16	7	0	(26)	1	15	19	7	-1	0	5	12	-1	14	22	0	100						
22	5	-1	4	9	14	17	6	(26)	4	17	15	7	18	22	-1	12	15	8	-1	10	10	15	13	100					
23	0	-1	12	13	2	4	0	14	5	7	17	17	12	0	-1	18	(23)	10	-1	15	3	7	21	(36)	100				
24	11	-1	2	0	(23)	10	12	21	7	6	11	15	12	20	-1	3	0	18	-1	(26)	1	3	8	16	(26)	100			
25	12	-1	7	11	13	14	1	8	0	16	0	11	4	5	-1	8	10	5	-1	20	2	13	4	18	(29)	(68)	100		
26	11	-1	6	6	5	12	22	0	19	11	9	15	23	14	-1	1	9	3	-1	13	0	4	7	2	13	(23)	11	100	
27	5	-1	5	1	4	3	5	9	4	19	5	6	14	3	-1	10	4	15	-1	5	3	0	10	13	3	3	1	(24)	100
28	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
29	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
31	14	-1	8	8	10	9	8	10	4	19	13	21	16	3	-1	10	5	6	-1	3	17	0	1	12	11	16	9	1	
32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
33	11	-1	0	11	0	5	1	4	0	8	14	(34)	21	5	-1	10	5	0	-1	3	4	18	18	1	3	11	(30)	17	(2
34	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
35	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
36	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
37	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
38	2	-1	1	10	1	10	9	15	1	16	8	29	23	16	-1	-1	3	-1	-1	-1	3	12	16	9	-1	15	12	-1	
39	(27)	-1	3	3	11	13	9	12	1	17	0	25	13	0	-1	3	13	5	-1	1	12	1	21	7	12	0	6	13	
40	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
41	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
42	3	-1	17	3	9	1	12	11	(24)	9	9	18	10	12	-1	8	15	17	-1	10	11	21	2	1	10	14	9	7	
43	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
44	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
45	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
46	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
47	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
48	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
49	(24)	-1	7	14	(31)	(32)	3	13	7	16	2	(34)	19	23	-1	18	14	-1	-1	13	4	7	0	15	4	5	11	8	
50	17	-1	7	14	22	15	4	19	7	16	5	(35)	15	13	-1	0	8	0	-1	14	1	4	0	13	21	5	4	8	
51	7	-1	3	22	9	10	15	15	8	14	23	14	(31)	6	-1	12	10	13	-1	17	14	15	23	22	12	21	19	12	
52	11	-1	18	14	19	18	6	4	5	10	8	20	21	16	-1	5	17	6	-1	18	20	5	24	22	15	8	12	8	2

Table 3. Chi-Square correlation coefficients (X100) for pair-wise comparisons of skull characters scored by WFP and analysis of correlation between the characters and sex of the specimen (variable -1). Significant correlations are circled. Characters with fewer than five observations for the second-most-common state not included in the analysis (indicated by -1 in the body of the table).

CORRELATION COEFFICIENTS BETWEEN VARIABLES BASED ON CHI-SQUARE:

	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
29	-1																								
30	-1	-1																							
31	-1	-1	-1																						
32	-1	-1	-1	100																					
33	-1	-1	-1	-1	-1																				
34	-1	-1	-1	10	-1	100																			
35	-1	-1	-1	-1	-1	-1	-1																		
36	-1	-1	-1	-1	-1	-1	-1	-1																	
37	-1	-1	-1	-1	-1	-1	-1	-1	-1																
38	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1															
39	-1	-1	-1	14	-1	14	-1	-1	-1	-1	100														
40	-1	-1	-1	3	-1	3	-1	-1	-1	-1	14	100													
41	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1												
42	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1											
43	-1	-1	-1	8	-1	8	-1	-1	-1	-1	18	10	-1	-1	100										
44	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1									
45	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1								
46	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							
47	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1						
48	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1					
49	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1				
50	-1	-1	-1	0	-1	14	-1	-1	-1	-1	22	3	-1	-1	4	-1	-1	-1	-1	-1	-1	100			
51	-1	-1	-1	10	-1	9	-1	-1	-1	-1	21	23	-1	-1	14	-1	-1	-1	-1	-1	-1	(71)	100		
52	-1	-1	-1	7	-1	19	-1	-1	-1	-1	19	8	-1	-1	7	-1	-1	-1	-1	-1	-1	10	7	100	
53	-1	-1	-1	7	-1	19	-1	-1	-1	-1	10	13	-1	-1	16	-1	-1	-1	-1	-1	-1	19	18	19	100

CORRELATION COEFFICIENTS BETWEEN VARIABLES BASED ON CHI-SQUARE:

	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
-1	100																												
0	-1	-1																											
1	6	-1	100																										
2	1	-1	(76)	100																									
3	5	-1	1	8	100																								
4	(28)	-1	1	7	(73)	100																							
5	17	-1	2	1	2	0	100																						
6	4	-1	17	19	8	10	(32)	100																					
7	4	-1	1	1	9	8	(49)	19	100																				
8	16	-1	16	14	14	6	10	18	7	100																			
9	9	-1	6	1	5	4	2	10	6	(30)	100																		
10	24	-1	13	12	11	10	16	19	17	24	13	99																	
11	24	-1	13	12	25	16	9	20	9	17	11	27	100																
12	8	-1	2	6	(33)	(25)	20	12	-1	14	18	9	12	100															
13	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1														
14	(24)	-1	3	7	4	11	6	3	-1	14	23	16	13	10	-1	100													
15	12	-1	10	2	(26)	11	7	16	11	13	2	11	7	2	-1	6	100												
16	9	-1	6	16	19	13	(30)	13	16	15	17	9	13	12	-1	4	1	100											
17	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1										
18	(27)	-1	6	16	14	5	20	(30)	-1	9	4	(27)	12	12	-1	4	23	1	-1	100									
19	(23)	-1	3	9	12	4	11	19	6	14	4	8	20	20	-1	6	(28)	5	-1	(31)	100								
20	19	-1	11	11	6	2	14	(27)	28	6	9	16	21	10	-1	-1	(25)	0	-1	10	(44)	100							
21	7	-1	(27)	18	22	17	6	1	23	20	5	25	12	11	-1	1	3	14	-1	2	15	15	100						
22	2	-1	10	5	9	13	3	14	9	11	6	9	20	18	-1	0	17	15	-1	3	8	2	11	100					
23	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1				
24	19	-1	8	12	19	13	(26)	(26)	9	10	1	17	12	10	-1	4	7	17	-1	(27)	3	6	9	18	-1	100			
25	15	-1	0	16	12	1	12	12	4	8	3	11	15	20	-1	6	15	(34)	-1	10	6	4	10	14	-1	(62)	100		
26	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
27	6	-1	1	0	12	14	4	6	18	6	6	20	17	16	-1	-1	17	9	-1	13	13	3	5	5	-1	11	9	-1	10
28	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
29	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
31	7	-1	0	11	9	8	1	12	21	13	10	17	12	4	-1	11	10	18	-1	1	6	3	4	1	-1	3	3	-1	
32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
33	5	-1	4	0	5	10	0	0	2	10	0	13	27	4	-1	10	21	4	-1	4	10	(26)	10	3	-1	8	3	-1	(4
34	13	-1	7	8	-1	-1	5	4	-1	(29)	11	10	19	22	-1	11	-1	12	-1	5	4	5	14	-1	-1	3	16	-1	
35	12	-1	14	19	14	-1	5	3	-1	12	9	9	10	10	-1	-1	-1	10	-1	5	7	5	15	0	-1	13	3	-1	1
36	12	-1	14	19	14	-1	5	3	-1	12	9	9	10	10	-1	-1	-1	10	-1	5	7	5	15	0	-1	13	3	-1	1
37	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
38	3	-1	8	13	2	2	6	11	2	15	6	14	21	16	-1	-1	4	2	-1	8	5	1	3	8	-1	2	4	-1	
39	(27)	-1	2	6	4	8	10	4	24	10	9	20	20	3	-1	11	4	15	-1	1	14	10	9	13	-1	8	(25)	-1	
40	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
41	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
42	4	-1	13	13	13	9	1	16	(35)	14	22	6	14	18	-1	19	18	8	-1	1	10	5	3	17	-1	10	18	-1	1
43	8	-1	5	14	(27)	-1	17	3	-1	11	9	(27)	15	10	-1	-1	16	(53)	-1	10	2	-1	12	21	-1	3	6	-1	
44	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
45	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
46	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
47	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
48	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
49	24	-1	2	0	13	10	1	8	9	13	1	11	26	25	-1	-1	13	1	-1	18	(36)	14	13	2	-1	1	8	-1	
50	24	-1	5	17	(33)	(41)	1	12	15	12	2	18	17	-1	-1	-1	4	17	-1	-1	(30)	25	23	9	-1	8	12	-1	
51	2	-1	(25)	20	6	13	6	5	8	12	20	22	18	11	-1	12	11	6	-1	18	9	6	(31)	15	-1	13	9	-1	
52	14	-1	7	5	6	13	9	6	8	11	13	19	13	11	-1	(26)	4	13	-1	14	12	4	7	4	-1	13	5	-1	

Table 4. Chi-square correlation coefficients (X100) for pair-wise comparisons of skull characters scored by AVY and analysis of correlation betwe the characters and sex of the specimen (variable -1). Significant correlations are circled. Characters with fewer than five observations for the second-most-common state not included in the analysis (indicated by -1 in the body of the table).

CORRELATION COEFFICIENTS BETWEEN VARIABLES BASED ON CHI-SQUARE:

	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
28																									
29	-1																								
30	-1	-1																							
31	-1	-1	-1																						
32	-1	-1	-1	100																					
33	-1	-1	-1	-1	-1																				
34	-1	-1	-1	18	-1	100																			
35	-1	-1	-1	-1	-1	-1	100																		
36	-1	-1	-1	12	-1	15	-1	100																	
37	-1	-1	-1	12	-1	15	-1	(100)	100																
38	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1															
39	-1	-1	-1	19	-1	9	-1	-1	-1	-1	100														
40	-1	-1	-1	0	-1	1	11	10	10	-1	21	100													
41	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1												
42	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1											
43	-1	-1	-1	8	-1	5	6	4	4	-1	10	8	-1	-1	100										
44	-1	-1	-1	(33)	-1	-1	-1	8	8	-1	-1	5	-1	-1	4	100									
45	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1								
46	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							
47	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1						
48	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1					
49	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1				
50	-1	-1	-1	15	-1	6	5	-1	-1	-1	14	7	-1	-1	23	7	-1	-1	-1	-1	-1	100			
51	-1	-1	-1	26	-1	2	-1	-1	-1	-1	6	-1	-1	-1	(27)	12	-1	-1	-1	-1	-1	(87)	100		
52	-1	-1	-1	9	-1	18	23	11	11	-1	19	8	-1	-1	9	19	-1	-1	-1	-1	-1	7	6	100	
	-1	-1	-1	3	-1	21	11	19	19	-1	3	15	-1	-1	6	0	-1	-1	-1	-1	-1	21	7	9	100

One of the characters deleted because of low repeatability (no. 4) was also significantly correlated with sex in both of the data sets. Because many of the specimens available from the Black Sea are of unknown sex (Perrin, Sokolov and Kuzmin, unpub.), the other character in this category (no. 39) will also be deleted from the character set.

Of the five character pairs with significant within-pair correlation in both character sets, either one or both members of the pair will be deleted from three based on low observer agreement as described above. For the other two such character pairs, only the left-side member of the pair will be taken for the geographical comparisons; this involves deletion of nos. 2 and 6 from the character set.

In two cases, character pairs 22-23 and 35-36, significant correlation was found between the pair members for one data set, but the analysis was not possible for the other (because of fewer than 5 observations in one or more states). These pairs will also be deleted: characters nos. 22, 23, 35 and 36.

After the deletions, 26 characters remain in the set; these will be used in the comparisons of the eastern Pacific and Black Seas series of skulls.

A further modification to the character set will be to assign three possible states for all characters that are not counts of foramina, with the third state being "intermediate", "at the level", or "uncertain", as appropriate. This will allow more homogeneous analysis and interpretation of the data.

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LITERATURE CITED

Perrin, W. F. 1975. Variation of spotted and spinner porpoise (genus Stenella) in the eastern Pacific and Hawaii. Bulletin Scripps Institution Oceanography 21, 206 p.

Perrin, W. F., M. V. Mina, G. J. Walker and J. Barlow. Unpub. Narrative report of joint research at the Southwest Fisheries Center, La Jolla, California, 26 March to 6 April, 1984. Ms, 5 p.

Perrin, W. F., M. D. Scott, G. J. Walker and V. L. Cass. 1985. Review of geographical stocks of tropical dolphins (Stenella spp. and Delphinus delphis) in the eastern Pacific. NOAA Technical Report NMFS 28, 28 p.

Perrin, W. F., A. S. Sokolov and A. A. Kuzmin. Unpub. Catalog of cetacean osteological specimens in collections of the Academy of Sciences, Leningrad, and Moscow State University. Ms, 53 p.

Perrin, W. F., A. V. Yablokov and V. L. Cass. 1982. Preliminary report on the use of non-metrical skull characters to discriminate populations of pelagic dolphins. Southwest Fisheries Center Administrative Report LJ-82-14, 32 p.

Yablokov, A. V., W. F. Perrin and M. V. Mina. 1983. Evaluation of phenetic relations among groups of dolphins using analysis of non-metric cranial variation. Zoologicheskiy Zhurnal 62:1887-1896. (English summary).

APPENDIX 1
DESCRIPTION OF NON-METRICAL CHARACTERS USED IN STUDY OF DELPHINUS DELPHIS

IN DORSAL VIEW

1. Position of anterior edge of mesial infraorbital foramen (a in Fig. 2) relative to the level of the anteriormost projection of the antorbital process, on left side. Note: the level of the antorbital process must be determined accurately; this is best done with a flexible ruler or other straight-edge.

   Codes: 1 = at or ahead, 2 = behind the level

2. Same on right side.

3. Cross-sectional shape of prenarial gutter at level of anterior edge of mesial infraorbital foramen, on left side.

   Codes: 1 = no overhang, 2 = overhang or closed, 3 = uncertain

4. Same on right side

5. Position of posterior edge of lateral infraorbital foramen (first, if more than one on each side) (b in Fig. 2) relative to posterior edge of mesial infraorbital foramen (a in Fig. 2).

   Codes: 1 = at or ahead, 2 = behind the level

6. Same on right side.

7. Relative positions of posterior edges of two lateral infraorbital foramina (anteriormost, if more than one on each side) (b in Fig. 2). Caution: the foramina may be unusually far forward, between the maxillaries and premaxillaries, and not visible in dorsal view.

   Codes: 1 = left foramen more anteriorly placed,
   2 = right foramen more anteriorly placed,
   3 = at same level, or uncertain

8. Number of vertical perforations (visible in vertical dorsal view) of facial area of maxillary by foramina, on left side.

   Codes: 1 = 1, 2 = 2, 3 = 3,.....,9 = 0

9. Same on right side.

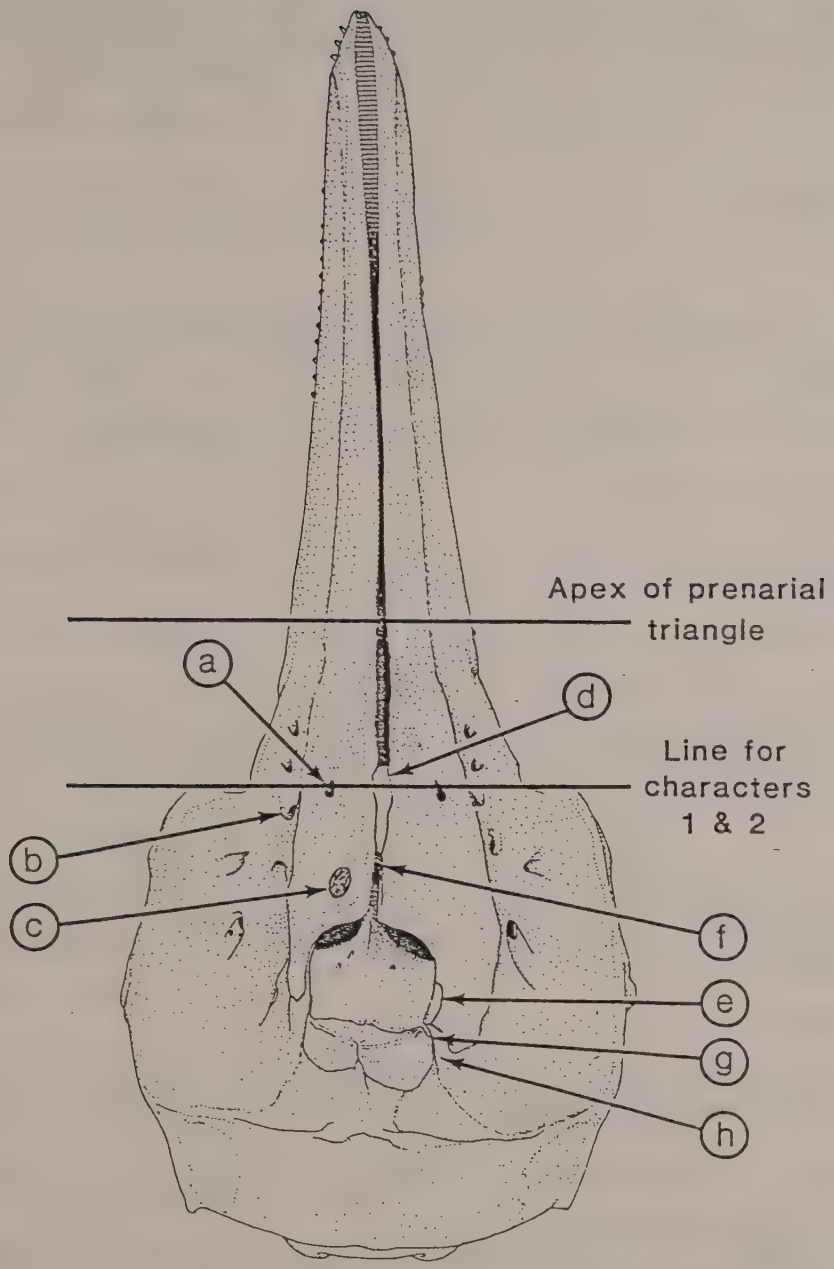

Figure 2. Dorsal view of dolphin skull, showing features mentioned in descriptions of non-metrical characters.

10. Total number of foramina in facial area of maxillary posterior to apex of prenarial triangle, on left side. Notes: Do not include slit-like openings between premaxillary and maxillary anterior to base of rostrum. The skull should be examined from all angles to detect very small foramina not visible in vertical view. Include all foramina with diameter >1/2 mm. If foramen divides below the surface, count as only one.

    Codes: 1 = 1, 2 = 2, 3 = 3,.....,9 = 0

11. Same on right side.

12. Isolated (from edge of bone) exposure(s) of maxillary through premaxillary in the prenarial shield (c in Fig. 2), on left side.

    Codes: 1 = present, 2 = absent, 3 = uncertain

13. Same on right side.

14. Dorsal projection of mesethmoid between premaxillaries near base of rostrum (d in Fig. 2).

    Codes: 1 = below surface of premaxillaries,
    2 = at or above surface
    3 = uncertain

15. Exposure of maxillary between premaxillary and mesethmoid shield (e in Fig. 2), on right side.

    Codes: 1 = present, 2 = absent, 3 = uncertain

16. Contact or near-contact (<1mm gap) between premaxillaries (or exposed maxillaries) in prenarial triangle (f in Fig. 2). Caution: the skull must be rotated to allow detection of overlapping bones.

    Codes: 1 = present, 2 = absent

17. Contact between premaxillary and nasal (no intervening bones), on left side (g in Fig. 2).

    Codes: 1 = present, 2 = absent

18. Same on right side.

19. Contact or near-contact between maxillary and nasal (no intervening bones) on right side. Caution: the skull must be rotated to insure seeing small intervening projection of frontal bone, which may be at a slightly lower level (inset).

    Codes: 1 = present, 2 = absent

20. Projection of maxillary extending forward between nasal and premaxillary (or premaxillary and frontal) on right side (as in h in Fig. 2).

    Codes: 1 = present, 2 = absent, 3 = uncertain

21. Relative extension of ascending process of left premaxillary. Note: do not confuse with anterior extension of nasal between premaxillary and maxillary.

    Codes: 1 = beyond anterior edge of left nasal,
    2 = not beyond anterior edge of left nasal

22. Contact between maxillary and occipital (dorsal to temporal crest), on left side. Note: end of premaxillary must be located accurately, on left side.

    Codes: 1 = present, 2 = absent

23. Same on right side.

IN LATERAL VIEW

24. Lateral hiatus (or foramen) between palatine and alisphenoid (a in Fig. 3), on left side. Caution: do not confuse with more dorsal (vertical) foramen through alisphenoid into nares. The hiatus is sometimes only a small slit; include if >1mm wide.

    Codes: 1 = present, 2 = absent, 3 = uncertain

25. Same on right side.

IN OCCIPITAL VIEW

26. Shape of foramen magnum (Fig. 4).

    Codes: 1 = piriform, 2 = smooth oval, 3 = uncertain

27. Symmetry of foramen magnum, including positions of small notch(es) and general shape.

    Codes: 1 = symmetrical, 2 = asymmetrical, 3 = uncertain

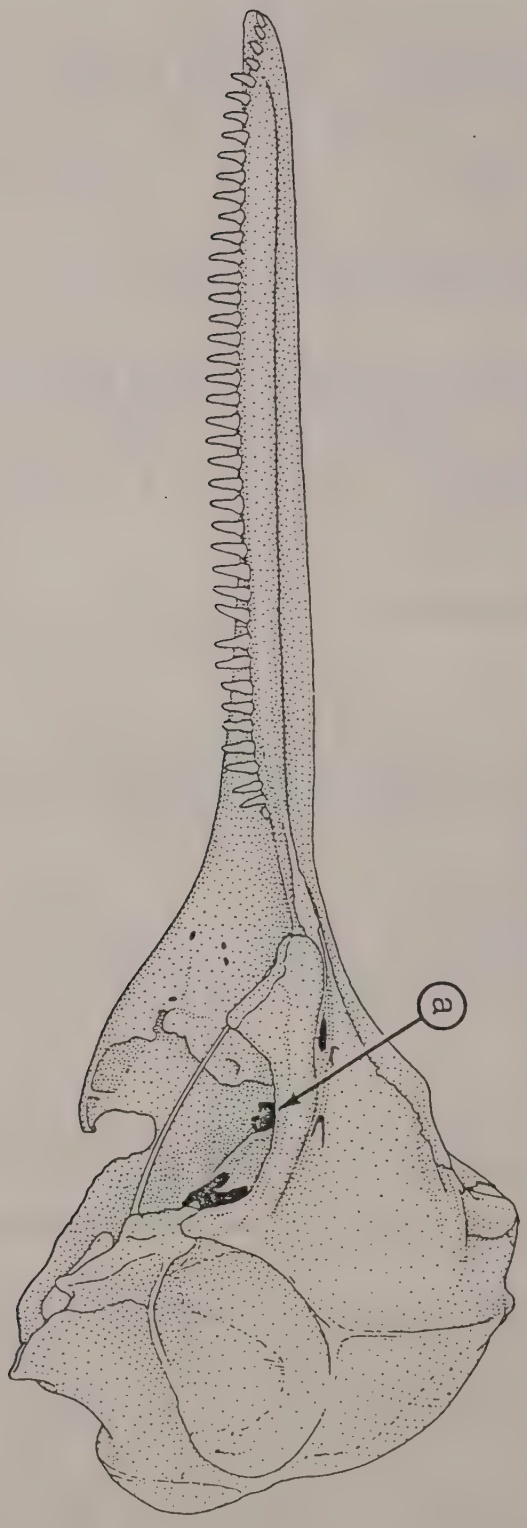

Figure 3. Lateral view of dolphin skull, showing features mentioned in descriptions of non-metrical characters.

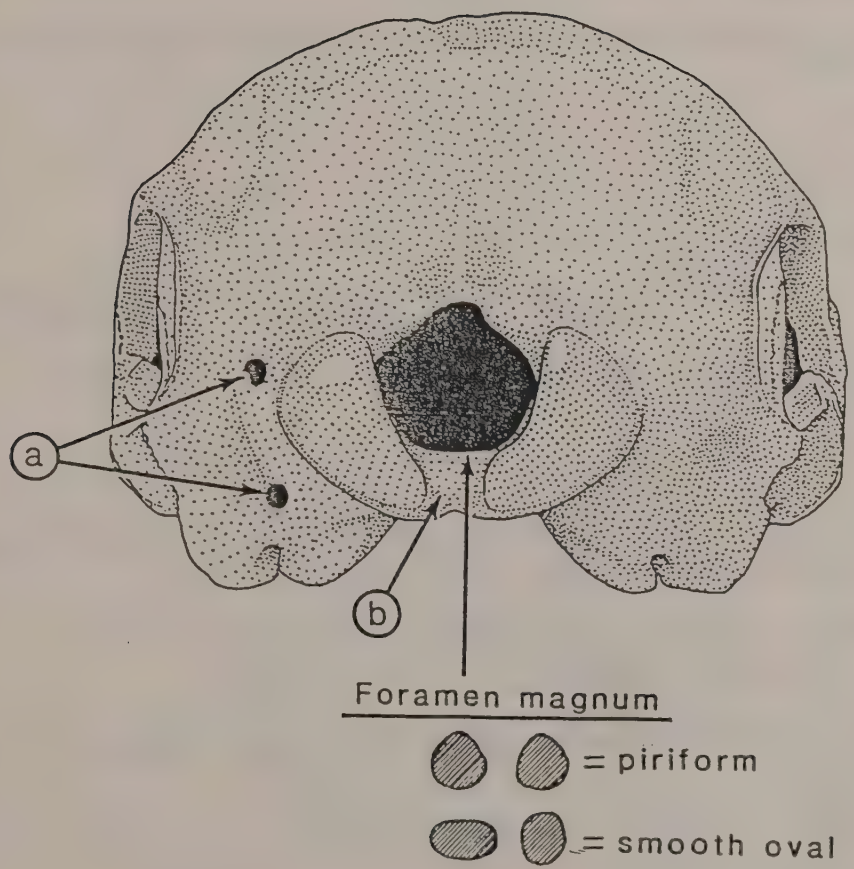

Figure 4. Occipital view of dolphin skull, showing features mentioned in descriptions of non-metrical characters.

28. Number of fenestrations in occipital (near foramen magnum) and exoccipital (a in Fig. 4), on left side.

Codes: 1 = 1, 2 = 2, 3 = 3,.....9 = 0

29. Same on right side.

30. Groove between occipital condyles (b in Fig. 4).

Codes: 1 = clearly present,
2 = clearly absent,
3 = nearly absent, or uncertain

IN VENTRAL VIEW

31. Small foramen between occipital condyles in basoccipital (a in Fig. 5).

Codes: 1 = present, 2 = absent, 3 = uncertain

32. Fenestrations in basioccipital (b in Fig. 5).

Codes: 1 = present and clearly natural,
2 = absent
3 = opening present but possibly only postmortem damage, not fenestration (= uncertain)

33. Overall shape of posteriormost edge of basiphenoid at basoccipital (c in Fig. 5).

Codes: 1 = straight, 2 = indented, 3 = uncertain

34. Position of posterior end of basisphenoid (c in Fig. 5) relative to line connecting mesial ends of sutures between alisphenoids and exoccipitals (d in Fig. 5).

Codes: 1 = behind (ignoring small irregularities),
2 = in line or ahead
3 = uncertain

35. Lateral fenestration in basisphenoid (e in Fig. 5), on left side.

Codes: 1 = present, 2 = absent

36. Same on right side.

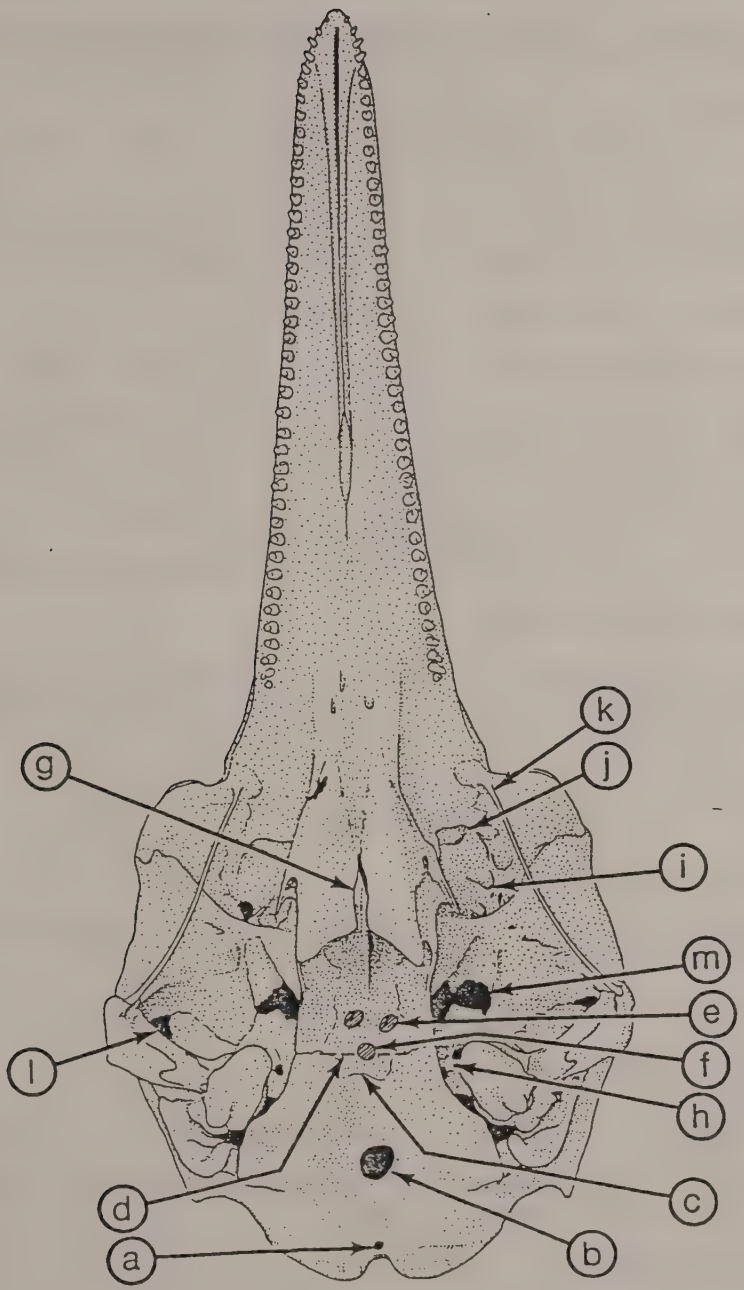

Figure 5. Ventral view of dolphin skull, showing features mentioned in descriptions of non-metrical characters.

37. Mesial fenestration in basisphenoid (f in Fig. 5).

Codes: 1 = present, 2 = absent

38. Gap between pterygoid hamuli (g in Fig. 5). Note: if gap is closed posteriorly, consider sides parallel.

Codes: 1 = widening anteriorly,
2 = widening posteriorly,
3 = parallel, or uncertain

39. One or more fossae between the mesial and posterior lacerate foramina (h in Fig. 5), on left side.

Codes: 1 = present, 2 = absent

40. Same on right side.

41. Position of interior opening of supraorbital foramen (h in Fig. 5), on left side.

Codes: 1 = behind (under) frontal trabeculum (hidden in perpendicular view),
2 = anterior to frontal trabeculum (visible)

42. Same on right side.

43. Position of anterior edge of large ventral foramen in maxillary (j in Fig. 5) relative to posterior edge of base of jugal (k in Fig. 5), on left side.

Codes: 1 = at or anterior to edge of jugal,
2 = posterior to edge

44. Same on right side.

45. Foramen-like fossa in internal roof of temporal fossa (l in Fig. 5; shown on right side), on left side.

Codes: 1 = present, 2 = absent, 3 = uncertain

46. Same on right side.

47. Configuration of optical hiatus (m in Fig. 5), on left side.

Codes: 1 = perforated in perpendicular view (>1mm opening),
2 = not perforated

48. Same on right side.

49. Position of posterior edge of foramen (anteriormost, if more than one) between basoccipital and exoccipital processes (n in Fig. 5), on left side.

Codes: 1 = external to base of notch,
2 = internal,
3 = intermediate, or uncertain

50. Same on right side.

MANDIBLE

51. Number of mental foramina, in left ramus.

Codes: 1 = 1, 2 = 2, 3 = 3,....., 10 = 10

52. Same on right side.